STEAM QUALITY MEASUREMENTS USING A RADIOACTIVE TRACER

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Lieutenant, United States Navy

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the requirements for the degree of

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IN

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ABSTRACT

The problem of steam quality determination (i.e., the ratio of the weight of saturated water vapor to the total weight of a mixture of saturated water vapor and saturated water droplets) has once more assumed importance in the steam power plant. This is due to the use of wet steam as produced by boiling water nuclear reactors. The rather difficult problem of measuring the quality of high pressure steam mixtures from the reactor in the range of 80 to 100% quality using steam calorimeters is complicated by the fact that the discharge from such calorimeters is radioactive. It has been proposed that the quality be measured making use of this radioactivity by means of an activity ratio, ρ, which compares the radioactivity of the mixture to the radioactivity of the feedwater.

In this investigation, it was attempted to correlate the results of measuring the quality of saturated steam by two methods: 1) mechanically separating the water vapor from the water droplets, and 2) by determining the activity ratio. A variation in quality of from 75 to 97% for low pressure steam was achieved by varying the flow of water containing a radioactive tracer, sodium 24, into a steam line through which passed 99.8^{+}% saturated steam. For each mixture the quality was obtained downstream of the mixing section by separating the two phases. At different quality readings a sample of the steam-water mixture was taken at the end of the mixing section, condensed, its radioactivity measured and then compared to the radioactivity of the feedwater yielding an activity ratio. It was possible to establish a theoretical relationship between the quality of the steam and this activity ratio, such that $\rho = 1 - x$. The quality of the steam-water mixtures and the activity ratio over the range of 75 to 97% quality were then compared.

It was found that the results were reproducible but the quality as determined by the activity ratio was somewhat higher than that determined by mechanically separating the two phases. The reasons for this variation are not apparent at present.

The investigation was conducted at the U. S. Naval Postgraduate School, Monterey, California, from February to May, 1959.

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1. Introduction

The feasability of using a radioactive tracer for steam quality determination was first demonstrated in 1955 by E. E. Coulter and T. M. Campbell [1][1]. Their tests were made on laboratory apparatus which operated at pressures up to 100 psi and on several boilers whose operating pressures range from 130 to 2150 psi. Their findings indicated that this method is suitable for small laboratory tests and may be extremely useful in measuring mechanical carry-over from boiling water nuclear reactors.

The Atomic Power Equipment Department of the General Electric Co. San Jose, California in conjunction with the Pacific Gas and Electric Co. conducted a series of tests on the General Electric Boiling Water Reactor at Vallecitos, California, in December of 1957. By varying the water level in the reactor, the particulate carry-over from the reactor was entrapped in 3 liters of steam condensate and analyzed on a 256 channel analyzer. The particulate carry-over from the reactor contained 1/2 part per million of sodium hydroxide and 0.01 micro-curies per cubic centimeter of sodium 24 which had been generated in the reactor. A decontamination factor (DF) equal to the ratio of the activity per gram of reactor water to the activity per gram of steam was found for each water level and it was then postulated that the quality of the steam (x) was related to the decontamination factor by:

$$x = 1 - \frac{1}{DF} \qquad (1)$$

[1]Brackets refer to Bibliography

The above relationship can also be derived by using basic definitions and assumptions as follows:

In the operation of boiling water reactors it is assumed that any water present in the steam line is due to water carry-over from the reactor itself. Under ideal conditions it can also be assumed that none of the water carried over is vaporized in the steam line and that no steam condenses in the steam line. Now if a sample of the steam-water mixture were taken, its radioactivity measured and compared to an equal volume of reactor feedwater an activity ratio, ρ , can be found by:

$$\rho = \frac{\text{activity steam-water mixture}}{\text{activity reactor feedwater}} \qquad (2)$$

or

$$\rho = \frac{s'}{s} \qquad (3)$$

If a known volume of liquid with a known specific activity is diluted it can be shown that[2] :

$$s' = \frac{s \quad V_w}{V_w + V_s} \qquad (4)$$

where V_w = original volume of water

V_s = volume of steam condensed and added to V_w in the steam-water mixture

s' and s are defined by (2) and (3)

Steam quality is defined as[3]

$$x = \frac{\text{mass of vapor}}{\text{mass of vapor plus mass of water}} \qquad (5)$$

or

$$x = \frac{m_v}{m_v + m_w} \qquad (6)$$

[2] W. J. Whitehouse and J.L. Putnam, Radioactive Isotopes, Chapter VII, p. 284

[3] P. J. Kiefer, G. F. Kinney, and M. C. Stuart, Principles of Engineering Thermodynamics, Art. 8-3, p. 127

Re-arranging (6) results in

$$\frac{m_v}{m_w} = \frac{x}{1 - x} \tag{7}$$

Substituting (4) in (3) gives

$$\rho = \frac{V_w}{V_w + V_s} \tag{8}$$

By definition v (specific volume) $\equiv \frac{V}{m}$ (ft^3 /lb) so that

$$\rho = \frac{m_w v_w}{m_w v_w + m_s v_s}$$

or dividing through by $m_w v_w$

$$\rho = \frac{1}{1 + \frac{m_s v_s}{m_w v_w}} \tag{9}$$

Substituting (7) in (9) gives

$$\rho = \frac{1}{1 + \frac{x}{1 - x} \frac{v_s}{v_w}} \tag{10}$$

However, $\frac{v_s}{v_w} = 1$ as v_s the specific volume of the steam condensed and v_w the specific volume of the water are equal. Therefore,

$$\rho = \frac{1}{1 + \frac{x}{1 - x}}$$

or $\rho = 1 - x$

i. e., the activity ratio is theoretically one minus the quality.

2. Equipment

The equipment, referring to Figure 1, consisted of a flow system in which steam was taken from the base steam line at about 120 psig. and piped to a 1/2" Centrifix Type RA separator, which extracted any moisture present to give 99.8^{+}% saturated steam. The almost dry steam then passed through a 4' section of 2" pipe with openings for a pressure gauge, U-path steam calorimeter, and an opening for a 1/2" water supply line leading to the water spray nozzle. The mixture of steam and water then went through a 10' vertical section to insure complete mixing with an opening for a sampling nozzle as used by the steam calorimeter. The sampling nozzles were installed in accordance with the 1929 ASME code with the perforations facing the flow. The mixture of steam and water then passed through a 2' section containing a 2" Centrifix Type RA separator for separation of the two phases. The remaining steam entered an 8' section of 2" pipe with openings at the end for a pressure gauge and a U-path steam calorimeter. The steam flow was then reversed through a Fisher Porter Co. Series 50 armored vapor Flowrator meter. The steam flow then passed through varying sizes of pipe in order to prevent "choking" of the steam as the pressure was reduced to a condenser operating at 24-25 inches vacuum. The condensate from the condenser was pumped either to an outside storage tank for containment of any radioactive material or to a weighing scale for weighing and determination of the flow rate of the steam.

The water to be mixed with the steam was supplied from a 50 gallon tank in which had been placed 10 millicuries of sodium 24 in the form of sodium chloride in solution. The tank was located approximately 10'

above the floor level in order to isolate the radioactive source. Suction was taken from the bottom of the tank by a centrifugal water pump which discharged either back to the supply tank or through a liquid Flowrator meter. After the liquid Flowrator meter the water passed through two sections of 4" pipe containing a Chromalux MTI 4 KW heater followed by a Chromalux MTS 270B 7 KW heater. The heated water then passed through piping housing a thermocouple and into the steam line through a Chicago Fulljet spray nozzle, size 3030.

The 2" Centrifix Type RA separator was fitted with a liquid collecting tank and a sight glass. The drain from the collecting tank was connected to a large tank type counter-flow heat exchanger. From the heat exchanger the water passed either to an outlet for weighing or returned to the supply tank.

The sample of the steam-water mixture was collected from a small 10-coil counter-flow heat exchanger.

The drain of the 1/2" Centrifix Type RA separator was utilized to heat the water in the 50 gallon supply tank.

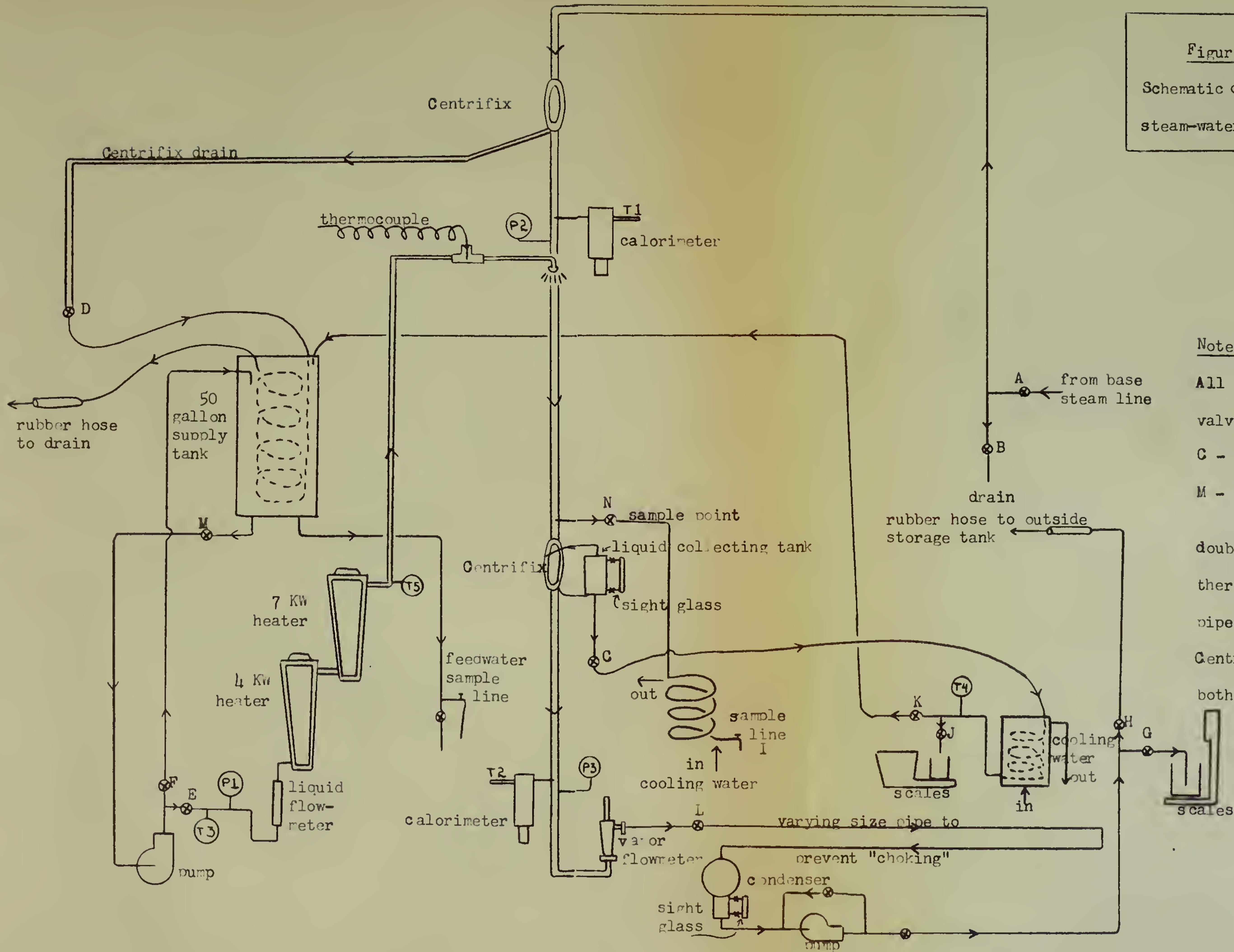


Figure 1

Schematic diagram of

steam-water flow system

Note:

All valves are globe valves except -

C - needle valve

M - quick acting gate valve

double lines indicate thermal insulation on pipes, around both Centrifixes, and around both heaters.

3. Operation

Reference is made to Figure 1 for value identification and part location.

After the water in the supply tank was heated to 170-180 degrees Fahrenheit valve D was left partially open to keep the water in the tank at that temperature. Then the valve in sample line I was slightly opened to insure a steady flow of the steam-water mixture in the sample line. This was necessary since any opening or closing of valves destroyed the equilibrium of the system.

The condensate from the condenser was diverted from the outside storage tank by valves G and H. By keeping the water level steady in the sight glass adjacent to the condenser so that the amount of water condensed was equal to the steam flow, the steam flow rate could be determined by weighing the condensate from the condenser. The float indicator on the vapor Flowrator meter was noted in order to be used later as a reference.

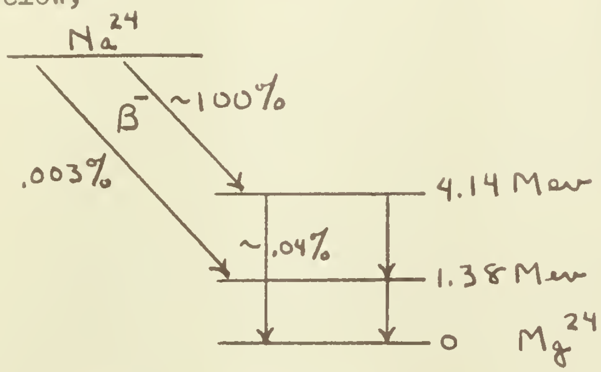
The condensate from the condenser was diverted to the outside storage tank for containment of any radioactive material. The flow of water for the desired quality was regulated by valves E and F. The heaters were adjusted as outlined in Appendix I until the temperature of the water being sprayed into the steam line was within two degrees of the saturation temperature of the steam. The temperature of the water being sprayed into the steam line was found by use of the thermocouple. Valve C was adjusted to maintain a steady level in the sight glass of the liquid collecting tank. The mass flow rate of water being sprayed into

the steam line as indicated by the liquid Flowrator meter was checked by either weighing the water being removed from the Centrifix or checking the time for the water to rise two inches in the sight glass. The capacity of two inches of the Centrifix sight glass was determined to be 1.55 pounds. Conditions were considered satisfactory when the two mass flow rates were equal to each other or to within 10% of each other for the high flow rates. For the flow rates to agree to within 10% resulted in the qualities to agree to within 2%. The 2"piping was insulated, as well as other piping, in order to minimize the possibility of any steam condensing in the line.

Radioactivity measurements were taken as outlined in Appendix II for each quality reading.

4. Radiation Counting

The samples were counted in a 3 x 3" well-type sodium iodide (NaI) scintillation crystal, surrounded by 2" of lead. The sample which is either the feedwater or the condensed steam-water mixture contains radioactive sodium 24 (Na^{24}) which emits gamma rays as it decays as illustrated below;[1]



Gamma rays are short electromagnetic radiations in the x-ray region and shorter given off by an excited nucleus. In this case the excited nucleus is Magnesium 24 (Mg^{24}) resulting from the change of a neutron into a proton in the nucleus of the radioactive sodium 24 as it decays.[2] The energies of the gamma radiation are 2.76 Mev and 1.38 Mev. The counter was biased for 0.1 Mev so that both gamma ray energies were detected and counted at all times. The remaining equipment consisted of the associated photo-multiplier tube, pre-amplifier, Atomic Non-overloading Linear Amplifier, and a Berkeley Decimal Scaler for the detection and counting of the gamma rays [2].

[1] Radiological Health Handbook, PB 121784, U. S. Dept. of Health, Welfare, and Education, Jan., 1957, p. 211

[2] Irving Kaplan, Nuclear Physics, August, 1956, Chapters 14 and 15

5. Method of Calculations.

a. Quality of the steam prior to spraying water into the steam line.

$$x = 100 - m \qquad (1)$$

$$m = \frac{100 \left[H - h - k\,(T - t) \right]}{L} \qquad (2)$$ [1]

where x = quality of saturated steam

m = percentage of moisture present in steam

H = enthalpy of saturated vapor at measured pressure (h_g)

h = enthalpy of saturated vapor at pressure in calorimeter (h_g)

k = specific heat of superheated steam

T = temperature of superheat in calorimeter

t = temperature due to the pressure in the calorimeter

L = heat of vaporization at measured pressure (h_{fg})

Typical of each days run is the following:

P (atmospheric) = 30.29" Hg. = 14.88 psi
Psig = 55
T = 272 degrees Fahrenheit
t = 212.64 degrees F.
From the steam tables
H = 1180.56 BTU/lb.
h = 1150.64 BTU/lb.
k = 0.48 BTU/lb-°F.
L = 908.06 BTU/lb.

$$m = \frac{100 \left[1180.56 - 1150.64 - .48\,(272 - 212.64) \right]}{908.06}$$

m = 0.1563%

x = 100 - m

x = 99.84%

[1] Ellison Draft Gage Co. Inc., How to Use the Ellison U-Path Steam Calorimeter, p. 7

The following calculations are for No. 6 Appendix IV

b. Calculation of activity ratio

Background Count	(B 1)	1840	
Feedwater Count	(TS 1)	64735	
#1 steam-water sample	(S 1)	13800	(All counts are
#2 steam-water sample	(S 2)	13900	for 10 minutes)
Feedwater Count	(TS 2)	62500	
Background Count	(B 2)	1800	

$$\rho_1 = \frac{S\,1 - B\,1}{TS\,1 - B\,1} = \frac{11960}{62895} = 0.190$$

$$\rho_2 = \frac{S\,2 - B\,2}{TS\,2 - B\,2} = \frac{12100}{61700} = 0.1995$$

c. Calculation of steam-water mixture quality

1) Quality as determined by flow of radioactive liquid to test section measured by the Fisher Porter liquid Flowrator meter.

steam flow (by weighing the condensate from the condenser) = 1030 pph.

liquid Flowrator meter scale reading = 128

This scale reading corresponds to a flow rate of 0.27 gpm at 182°F or 131 pph.

$$\text{Quality} = \frac{\text{pounds of steam per hour}}{\text{pounds of steam per hour plus pounds of liquid per hour entering the test section}}$$

$$= \frac{1030}{1030 + 131} = \frac{1030}{1161} = 0.887$$

2) Quality as determined by weighing the water separated by the Centrifix from the steam-water mixture after flowing through the test section.

water flow rate = one pound in 28 seconds = 128.6 pph

$$\text{Quality} = \frac{\text{pounds of steam per hour}}{\text{pounds of steam per hour plus pounds of water per hour leaving the test section}}$$

$$= \frac{1030}{1030 + 128.6} = \frac{1030}{1158.6} = 0.889$$

The qualities of 0.887 (measured by using water flow rate into the test section) and 0.889 (measured by weighing water flow rate from test section) agree to within 0.2% and the run is considered satisfactory.

d. Calculation of probable error in determining specific activity

$$r\ (\text{sample}) = \frac{67.45\sqrt{S\,1 + B\,1}}{S\,1 - B\,1} = \frac{67.45\sqrt{15640}}{11960} = 0.70\,\%$$

$$r\ (\text{feedwater}) = \frac{67.45\sqrt{TS\,1 + B\,1}}{TS\,1 - B\,1} = \frac{67.45\sqrt{66575}}{62895} = 0.276\%$$

e. Calculation of steam quality through lower calorimeter using formulas (1) and (2) above.

Pressure = 59 Psig	H = 1181.5 BTU/lb
Temp. = 268 °F	h = 1150.4 BTU/lb
Press. Atm. = 14.7 psia	L = 905.2 BTU/lb
	k = 0.48 BTU/lb -°F.

$$m = \frac{100\left[1181.5 - 1150.4 - 0.48\,(268 - 212)\right]}{905.2}$$

$m = 0.463\%$

$x = 100 - m$

$x = 99.54\%$

6. Results and Conclusions

While the range of qualities determined experimentally only covered the range of 75 to 95% quality it is evident from both graphs, Figure 2 - activity ratio versus 0 to 100% quality and Figure 3 - activity ratio versus 70 to 100% quality, that the experimental curve exhibits a trend similar to the theoretical curve, $\rho = 1 - x$. However, the reasons for the quality as determined by the activity ratio being somewhat higher than the quality as determined by mechanically separating the two phases are not apparent at present. It is doubtful that the higher specific activity is a result of some of the water vaporizing into steam. Conditions were considered satisfactory when: 1) the temperature of the water being sprayed into the steam line was within two degrees of the saturation temperature of the steam, and 2) the flow rate of water passing through the liquid flowmeter and the flow rate of water separated from the steam by the Centrifix agreed to within 10% at the most. This resulted in agreement with the qualities to within 2%. When the two flow rates, were not exactly equal but within the limits described above, the difference between the flow rates was not sufficient to account for the increase in specific activity. Whether or not the high specific activity is due to the inefficiency of the Centrifix is debatable. The two Centrifixes were chosen so that they would perform most efficiently in the operating range in question. This was proven by the measurement of the steam quality after the Centrifix. The steam quality was found to be $99.5\overset{+}{}\%$ at all times.

In plotting Figure 2 the average of the qualities and the average of the activity ratios were used to determine one point since the scale used for the graph was so small. For Figure 3 the separation of qualties

and activity ratios is shown by the dotted line which encircle the data for a single point. Figure 4 is a plot of % steam quality by weighing versus % steam quality by radioactive tracer.

That the experimental points are a good representation is shown by Run No. 6 with an average quality of 0.888 and an average activity ratio of 0.195 compared to Run No. 8 with an average quality of 0.891 and an average activity ratio of 0.192, indicating that this point is reproducible to within 0.33-1.5%.

FIGURE 2
ACTIVITY RATIO (ρ) VERSUS 0 TO 100 % STEAM QUALITY BY WEIGHING

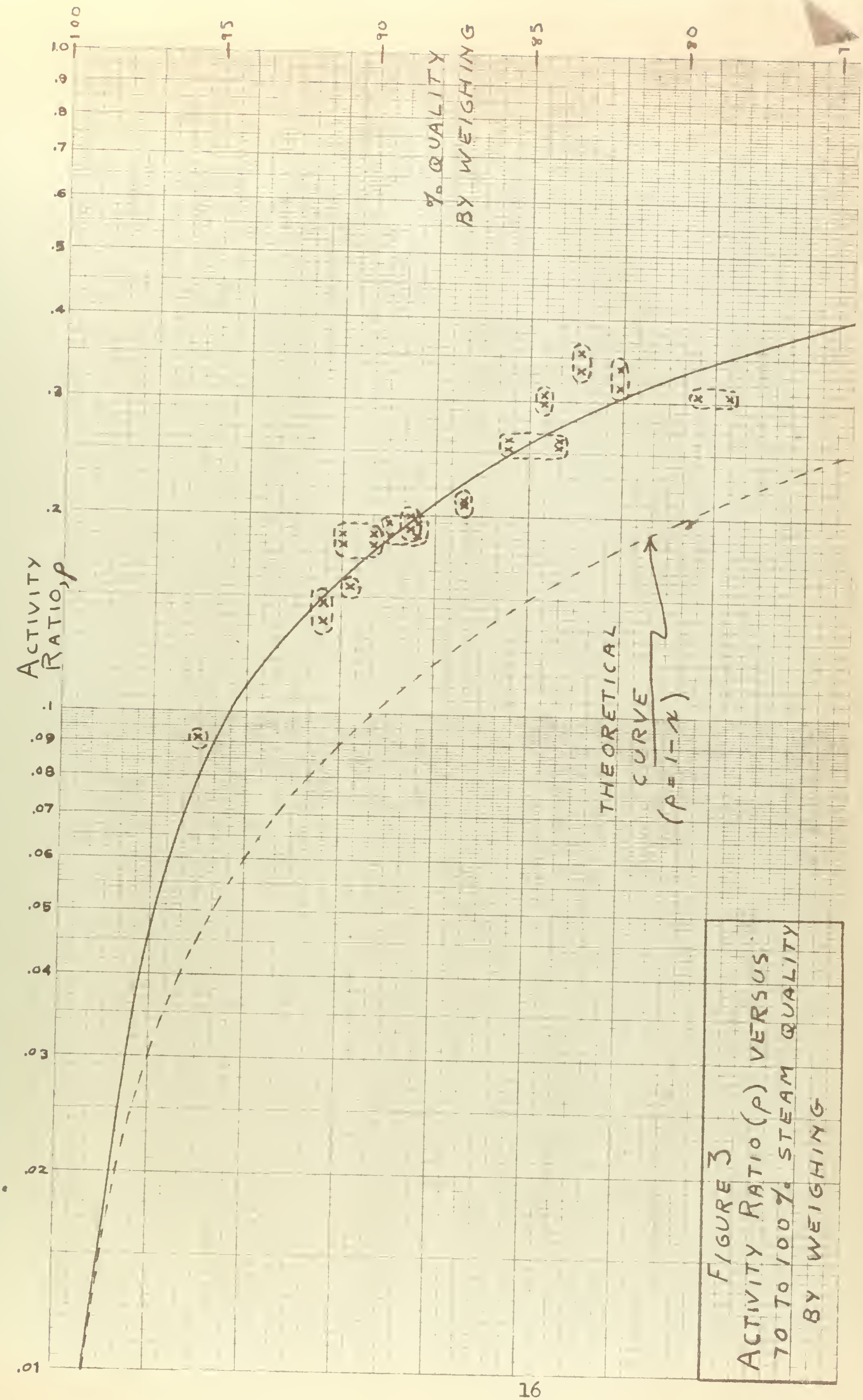
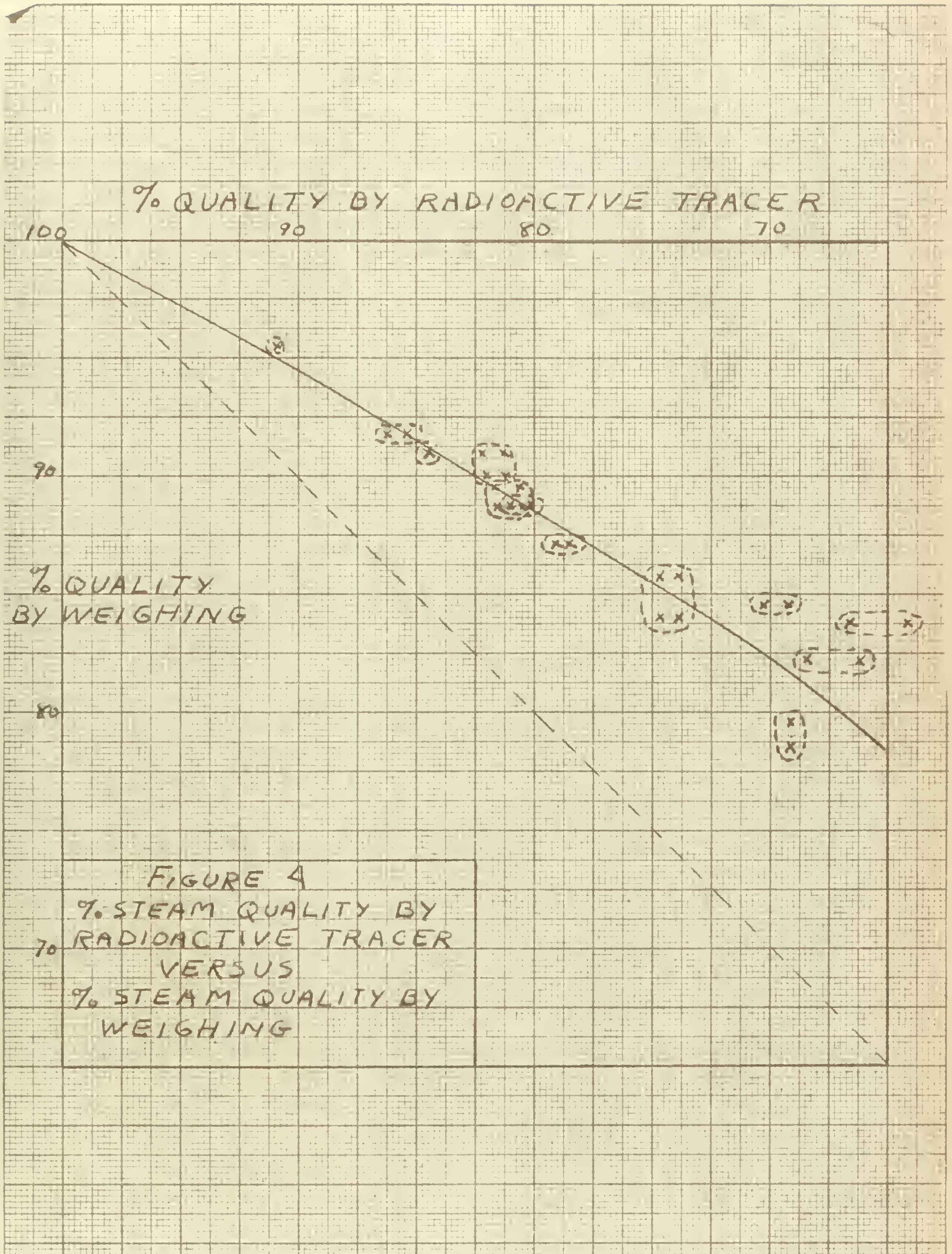


FIGURE 3
ACTIVITY RATIO (ρ) VERSUS 70 TO 100% STEAM QUALITY BY WEIGHING


% QUALITY BY RADIOACTIVE TRACER
100
90
80
70
% QUALITY BY WEIGHING
90
80
70
FIGURE 4
% STEAM QUALITY BY RADIOACTIVE TRACER VERSUS % STEAM QUALITY BY WEIGHING

APPENDIX I

HEATERS AND THERMOCOUPLE

With 220 volts across the 4000 watt heater and the resistance bank used to control the 7000 watt heater, there were 23.5 amps to the 7 KW heater and 16.5 amps to the 4 KW heater totaling approximately 4290 plus 4000 or 8290 watts available for heating. With a steady spray of water at 0.4 gpm (193 pph) and inlet water temperature of 195 degrees, the water temperature leaving the heaters was 315 degrees indicating that

$$H = \dot{m}_w \times c_p \times \Delta T \times \text{(conversion factor)}$$

$$= 193 \times 1 \times 120 \times 2.93 \times 10^{-4}$$

$$= 6.79 \text{ KW}$$

It had been estimated that about 8.29 KW were available so that the heaters were about 82% efficient. This is possible inasmuch as the base of the heaters are on a 2" flange in a 4" pipe, and the 4 KW heaters are only about 18" long in a 41" section of pipe. The thermocouple was found to lag the temperature gauge (T 5) by four degrees.

Another combination of the heaters used was to place both heaters across 220 volts for the maximum flow or lowest quality desired. The heaters could also be set up with 220 volts across the 7 KW heater and using the resistance banks to control the 4 KW heater. The wiring of the heaters was determined by the flow rate desired.

It was found that the steam entrance pressure varied from 66-68 psig., for which the associated saturation temperature range is 311-315 degrees. Depending on the flow rate being used, the heaters were used to heat the water to the saturation temperature as indicated by the thermocouple. The thermocouple was iron-constantan enclosed in stainless steel with iron-constantan wiring. It was first checked for accuracy

in a controlled oil bath, then calibrated by comparison with a thermometer under the same operating conditions, with the following results:

	reading	temperature	thermometer reading
thermocouple	7.37	280.94 °F.	282 °F.

APPENDIX II

SAMPLING TECHNIQUE

In order to produce justifiable results the same amount of liquid of the steam-water mixture and of the feedwater samples must be measured. This was done by having the same volume marked on all test tubes.

Inasmuch as the activity ratio, ρ , is a ratio the efficiency of the sodium iodide crystal and of the counter were not determined as any efficiency value used would cancel out in this ratio.

Due to the normal background count (i.e., cosmic rays, presence of radioactive source, etc.) the total number of counts, N, is found to be:[1]

$$N = N_m - B \pm \sqrt{N_m + B} \tag{1}$$

where N_m = the number of counts of the sample

B = the background count

The probable error is found to be:[1]

$$r = \frac{67.45 \sqrt{N_m + B}}{N_m - B} \tag{2}$$

For each quality reading determined, the following order was used:

at t = -1	#1 Background count	(#1B)	
t = 0	#1 Feedwater sample	(#1TS)	
t = 1	#1 Steam-water mixture sample	(#1S)	(All counts are for
t = 2	#2 Steam-water mixture sample	(#2S)	10 minutes)
t = 3	#2 Feedwater sample	(#2TS)	
t = 4	#2 Background count	(#2B)	

In calculating the activity ratio each sample was paired with its background count and feedwater sample. That is, for ρ_1 - #1S, #1TS, and #1B were used, and for ρ_2 -#2S, #2TS, and #2B were used.

[1] William E. Siri, Isotopic Tracers and Nuclear Radiations with Applications to Biology and Medicine, Sections 10-14 and 10-15.

APPENDIX III

SAFETY PRECAUTIONS

Permission to use the radioactive isotope, sodium 24, was granted by the Atomic Energy Commission as an amendment to License #4-2579-1 issued to the U. S. Naval Postgraduate School. Disposal of the radioactive water was made in accordance with para. 20.303 of the Federal Register [3], Disposal by release into Sanitary Sewerage Systems, which reads in part

> (b) (1) The quantity which, if diluted by the average daily quantity of sewage released into the sewer by the licensee, will result in an average concentration equal to the limits specified in Appendix B, Table 1, column 2 of this part.

The limits specified for sodium 24 are $2.4 \times 10^{-2} \mu c/ml$ (micro-curies per millimeter). The feedwater was made radioactive by the addition of 10 millicuries of radioactive sodium chloride in a one normal solution of hydrochloric acid to a 50 gallon tank of water. This is equivalent to $5.29 \times 10^{-2} \mu c/ml$. With a half life of 15 hours for sodium 24, the original radioactivity decays to $2.65 \times 10^{-2} \mu c/ml$ in 15 hours and $1.33 \times 10^{-2} \mu c/ml$ in 30 hours, which is below tolerance for disposal into the sewage system. However, the tank was used for four days so that it was well below the tolerance for disposal at the end of the experimental period.

While the radioactive source was present in the water all personnel working in the vicinity of the experimental apparatus wore film badges and the area was monitored with a geiger counter to ascertain that the levels were below the AEC limits of whole body radiation of 300 mr/week (blood forming organs, gonads, lens of eye) and 600 mr/week (skin at basal layer of epidermis).

The radioactive solution gave a reading of 25-30 mr/hour on the outside of the bottle upon arrival; it was immediately diluted in the 50

gallon tank reducing the radioactive hazard. The tank then gave a reading of 5 mr/hour at a distance of 1" from the outside of the tank.

APPENDIX IV

SUMMARIZED DATA

Run No.	Top Cal. Press. (Psig)	Thermo-couple rdg. (°F)	Steam flow (pph)	Water temp in (°F)	Water flow meter (pph)	Meter quality	Water flow out (pph)	Centrifix quality	Back-ground count	Total count	Sample Count	Activity Ratio	Sample probable error	Total probable error
									(All counts for 10 min. period)					
1	68.5	315	888	168	90	.908	90	.908	3840	210600	36400	.1565	.417	.151
									3700	204000	34487	.1559	.417	.151
2	70	314	648	180	31.6	.955	29.5	.956	3340	169340	18580	.0913	.654	.169
3	71.5	316	684	176	62.8	.917	63.5	.915	3200	162900	26850	.1482	.494	.172
									3170	162000	25000	.1379	.518	.173
4	71.5	316	684	176	76.4	.900	68	.910	3170	162000	31700	.180	.441	.173
									3150	161000	32600	.187	.431	.173
5	71.5	314	666	179	111	.858	126.5	.841	3150	161000	43000	.253	.364	.173
									3140	160000	44000	.261	.358	.174
6	69	314.5	1030	182	131	.887	128.6	.889	1840	64735	13800	.190	.701	.276
									1800	62500	13900	.1995	.696	.282
7	69	314	996	171	146.3	.872	145	.871	1800	62500	14510	.209	.679	.282
									1700	61300	14410	.213	.672	.284
8	69	315	996	169	115	.896	126.9	.887	1700	61300	12950	.1888	.723	.284
									1681	58100	11000	.195	.735	.292
9	68	315.5	666	173	122	.845	120	.847	1212	22100	7460	.299	1.00	.492
10	68	314.5	666	174	122	.845	120	.847	1210	21577	7475	.308	1.00	.498
11	68	314	666	176	143.2	.823	144	.822	1210	21577	7630	.315	.988	.498
									1200	20100	7570	.337	.99	.521
12	65	310	679	180	133.8	.835	139.8	.834	1240	21650	8550	.358	.911	.499
									1230	21550	7980	.332	.959	.501
13	69	314	702	167	192	.786	180	.796	1180	19500	6830	.308	1.07	.529
									1151	19280	6770	.310	1.068	.530

APPENDIX V

EQUIPMENT LIMITATIONS

a. Steam Flow

Although the steam flow was taken from the base line it was not a steady flow. Whenever steam was used elsewhere on the base a change in pressure would occur. This change in pressure would be indicated on the vapor flowmeter as a change in the steam flow. Prior to each run the condensate from the condenser was weighed and the steam flow rate determined. This steam flow rate and the reading on the steam flowmeter were used as a reference throughout the remainder of the run. When a sample was taken, the steam flowmeter was noted; and if the reading of the flowmeter was different than when the steam flow rate was first determined, the steam flow rate would be corrected accordingly. The use of a steam regulator installed prior to the test section would eliminate this variation in the steam flow rate.

While running, valve D was left partially open in order to keep the water in the supply tank up to temperature. From day to day, the valve setting was slightly different causing a variation in steam flow. This could be eliminated by using a different source to heat the water in the supply tank and not detract from the steam flow in the test section.

b. Sampling

While each test tube was marked with the same volume, it did not always happen that the same volume was measured each time. Due to the human element involved a small error in volume might occur as each test tube was being filled from the sample line. This would account for the fact that on some runs the sample had a higher specific activity for the second sample than for the first sample.

The time for the sample line to drain also had to be taken into account. With sample line I draining as fast as possible, it was found that it took one minute and twenty seconds to completely drain the line. Therefore, when a sample was to be taken there was a time lag involved to insure that the sample being measured was the same water as passing through the liquid flowmeter when used to determine that conditions were satisfactory.

c. Heating

It was stated that the heaters were found to be only about 82% efficient. This could be eliminated by having the heaters installed in casings which fitted their dimensions more closely. The 4 KW heater was 18" long installed in a section of pipe 41" long. The diameter of the casing pipe could also be decreased from 4" to 3". Thereby the efficiency of the heaters would be increased and larger flow rates or lower qualities could have been measured.

d. Number of Runs

Due to the short fifteen hour half life of sodium 24 the supply tank could only be used for about a four day period if the original source was of ten millicuries strength. Altogether approximately 30 runs were made. Of these 30 runs only 13 were considered satisfactory. Those runs not counted were considered unsatisfactory due to; 1) the flow rate of the water passing through the liquid flowmeter and the flow rate of the water separated from the steam by the Centrifix did not agree to within 10%, and 2) the temperature of the water being sprayed into the steam line was not within two degrees of the saturation temperature of the steam.

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